

PACCE: Perl Algorithm to Compute Continuum and Equivalent Widths

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Abstract

We present Perl Algorithm to Compute continuum and Equivalent Widths (PACCE). We describe the methods used in the computations and the requirements for its usage. We compare the measurements made with PACCE and “manual” ones made using IRAF *splot* task. These tests show that for SSP models the equivalent widths strengths are very similar (differences $\lesssim 0.2 \text{ \AA}$) for both measurements. In real stellar spectra, the correlation between both values is still very good, but with differences of up to 0.5 \AA . PACCE is also able to determine mean continuum and continuum at line center values, which are helpful in stellar population studies. In addition, it is also able to compute the uncertainties in the equivalent widths using photon statistics. The code is made available for the community through the web at <http://www.if.ufrgs.br/~riffel/software.html>.

Keywords Methods: data analysis; Line: Equivalent Widths; Techniques: Spectroscopy

1 Introduction

The equivalent widths (W_λ) of absorption lines, observed in the spectrum of astronomical sources can be seen as compressed, but highly informative, representation of the whole spectrum. For example, the W_λ

of the absorption lines observed in galaxies spectra reveals insights about their stellar populations, like the ages and metallicities of the stars which dominates the light of the host galaxy (e.g. Bica 1988; Schmitt et al. 1996; Rickes et al. 2004; Rembold & Pastoriza 2007; Krabbe et al. 2007, 2008; Riffel et al. 2008). Regarding the spectrum of a star, it is possible to make use of the W_λ of absorption lines to determine directly the fundamental atmospheric parameters such as: surface gravity ($\log g$), effective temperature (T_{eff}) and the chemical abundances of many elements (see for example Gonzalez & Lambert 1996; Feltzing & Gonzalez 2001).

However, the price to be paid when using the powerful informations contained in the W_λ is the long time needed to make a reliable measurement of this observables. Commonly, the W_λ are measured using interactive routines like *splot* provided by the IRAF¹ team or with independent codes like LINER (Pogge & Owen 1993). Both softwares are “hand operated”, which means the user need to look for the line limits and continuum points in the spectrum. The next step, is to mark them “manually”. This procedure is very time-consuming and introduce many uncertainties which are propagated to a posterior analyses of the quantities involving the W_λ measurements.

With the growing of spectral surveys (e.g. Sloan Digital Sky Survey), it becomes necessary to accelerate and automate some process such as the analysis of stellar populations of galaxies, as well as the determination of fundamental atmospheric parameters of individual stars. In order to help in such task we present in this paper a new automatic² code: *PACCE: Perl Algo-*

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²Also interactive, as the input parameters are easy to be changed.

rithm to Compute Continuum and Equivalent Widths. This software, written in PERL, can be used to compute the W_λ of absorption lines as well as to determine continuum points, being very helpful to perform stellar population synthesis following, for example the method developed by Bica (1988) and Schmitt et al. (1996).

This paper is structured as follows: In Sec. 2 we describe the system requirements as well as the numerical procedures behind the code. The input parameters and the outputs of the code are discussed in Sec. 3. A comparison with the measures made whit PACCE and “hand-made” measurements are presented in Sec. 4. The final remarks are made in Sec. 5.

2 The code

The idea behind PACCE is to reproduce the “manual” procedure used to measure the W_λ of absorption lines in a spectrum, as well as to measure mean continuum fluxes in defined regions and compute the continuum value at line center. In addition, using the same inputs, it does exactly reproduce the measured values being “user” independent (e.g. the uncertainties introduced by the user in “hand operated” procedures are removed), and thus allowing for a better comparison between W_λ measured by different users.

PACCE was written in Perl, allowing anyone to use it without having any problems with software licenses. It is freely distributed under GNU General Public License³(GLP). All the libraries used in the code are also free and distributed under GLP license. PACCE source code can be freely downloaded from <http://www.if.ufrgs.br/~riffel/software.html>. All requirements to run PACCE can easily be installed in any linux machine (e.g. *apt-get*, *synaptic* or *yum*), they are:

- Perl
(<http://www.perl.org>);
- Perl’s “Math::Derivative” package
(<http://search.cpan.org>);
- Perl’s “Math::Spline” package
(<http://search.cpan.org>);
- Gnuplot
(www.gnuplot.info).

In addition, we call the attention to the fact that Perl is installed as default in any linux flavor and PACCE can easily be converted to run under Microsoft Windows system (without plots).

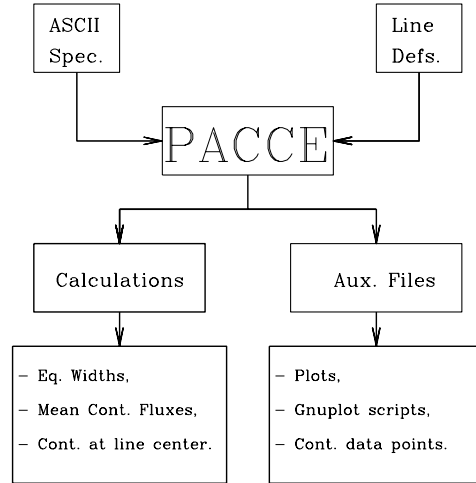


Fig. 1 Fluxogram describing the use of PACCE .

2.1 Calculations: Equivalent Widths and Mean Continuum Fluxes

2.1.1 Equivalent Widths

In general, absorption feature indices are composed by measurements of relative flux in a central wavelength interval corresponding to the absorption feature considered (line limits λ_l and λ_u in Fig. 2) and two continuum sidebands passband regions (spectrum ranges - dots - in the boxes of Fig. 2). Such sidebands provide a reference level (pseudo-continuum, solid line Fig. 2) from which the strength of the absorption feature is evaluated (see Worthey et al. 1994, for details). PACCE computes the pseudo-continuum, $F_c(\lambda)$, in three ways: (i) a linear regression is computed using all the continuum points in the passband regions and a straight line ($y=ax+b$) is computed using the regression coefficients; (ii) a straight line is drawn connecting the mid-points of the flanking passband continuum regions; (iii) as a cubic spline⁴. The form in which the pseudo-continuum is adjusted is chosen by the user (see Sec. 3).

Considering $F_i(\lambda)$ as observed flux per unit wavelength an W_λ is then:

$$W_\lambda = \int_{\lambda_l}^{\lambda_u} \left(1 - \frac{F_i(\lambda)}{F_c(\lambda)} \right) d\lambda \quad (1)$$

³<http://www.gnu.org/licenses/gpl.html>

⁴Such option is useful when measuring W_λ of absorption lines located close to emission lines, and thus, only points - not regions- of continuum free from emission/absorption are available

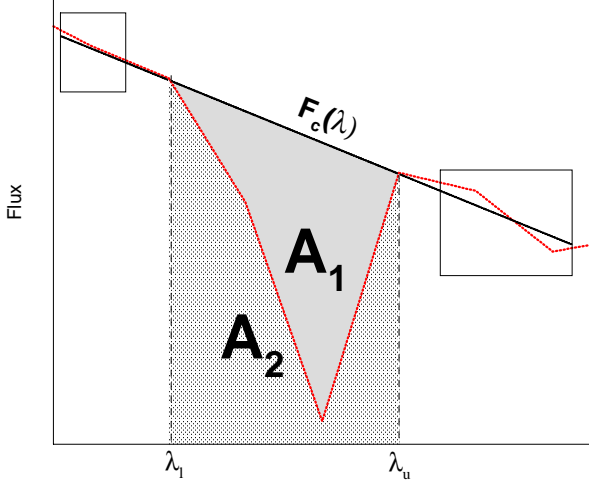


Fig. 2 Sketch of the definition of a hypothetical index. Sidebands continuum regions are represented by boxes. Solid line is the pseudo-continuum. Vertical lines represent the line limits λ_l and λ_u . Shaded region (A_2) is the area below the line limits and filled (A_1) region is the area of the line. Dotted line (red) represents the spectrum.

Considering Fig. 2 one can write the area A_2 as:

$$A_2 = \int_{\lambda_l}^{\lambda_u} F_i(\lambda) d\lambda \quad (2)$$

and, thus, the A_1 is the absorbed flux between λ_l and λ_u . Similarly, the area below the pseudo-continuum between λ_l and λ_u is:

$$A_1 + A_2 = C = \int_{\lambda_l}^{\lambda_u} F_c(\lambda) d\lambda, \quad (3)$$

thus, the W_λ of the absorption line between λ_l and λ_u can be written as:

$$W_\lambda = \left(1 - \frac{A_2}{C}\right) (\lambda_u - \lambda_l), \quad (4)$$

for more details see for example Vollmann, & Eversberg (2006).

In PACCE we compute both areas, A_2 and C , using the trapezium method. In addition, PACCE does compute the uncertainties in the equivalent widths, $\sigma(W_\lambda)$, considering the photon noise statistics pixel by pixel. For this purpose we follow Vollmann, & Eversberg (2006), assuming that the ratio between C and A_2 are similar to the normalized ratio between these quantities (for details see Vollmann, & Eversberg 2006). In the case of linear pseudo-continuum adjustment we estimate the signal-to-noise ratio (S/N) as being the ratio between the square root of the variance and the mean flux of the points in the bandpass interval (i.e. boxes in Fig. 2). In the case of a pseudo-continuum defined with

a cubic spline the S/N is calculate in the same way as in the linear adjustment, but using points in a region free from emission/absorption lines defined by the user (see Sec. 3).

2.1.2 Mean Continuum Fluxes

Besides the W_λ the code also computes the mean continuum fluxes (\bar{F}_λ , last line of Tab. 1) and the continuum at line center. Such measurements are useful, for example, to perform stellar population studies using the technique described by Bica (1988). The \bar{F}_λ point are calculated following the equation:

$$\bar{F}_\lambda = \frac{1}{N} \sum_{i=0}^{i=N} F_\lambda^i, \quad (5)$$

where F_λ^i is the flux of each λ in the defined interval and N is the number of points considered. The errors are estimated as being the square root of the variance. The continuum at the line center is taken as being the pseudo-continuum flux where $\lambda = \frac{\lambda_l + \lambda_u}{2}$.

3 Running PACCE

To run PACCE the user needs a ASCII, one dimensional, spectrum and a ASCII input table containing the line definitions. The ASCII spectrum is easily created using the *wspectext* IRAF task. An example of a input table is shown in Tab. 1. Note that the continuum points used to determine the line pseudo-continuum can be defined into three different ways (linear, mid-point or spline). The fact that such input table is very easy to be edited/created, makes PACCE also an interactive tool, allowing for fast changes and tests in W_λ and \bar{F}_λ measurements.

Besides the calculations, PACCE outputs some auxiliary files (Fig. 1). These files are the pseudo-continuum data points, the plots showing the regions used in the W_λ calculations (see Fig. 3), as well as the Gnuplot commands, which are stored for future use.

4 Testing PACCE

In order to test PACCE we perform “hand-made” measurements in a set of Maraston (2005) simple stellar population (SSP) models as well as in a library of observed stellar optical spectra (Silva & Cornell 1992).

In Fig. 4 we show a comparison ~ 3600 W_λ measured using PACCE and ‘hand-made’ measurements with IRAF *splot* task. We also plot the differences between

```
#####
#
#           Index definitions table example.
#
#####
# ID           Line Limits           Left side Cont.       Right side Cont.
#   LinearC      (4847.875,4876.625)  [4827.875:4847.875], [4876.625:4891.625]
#   MidPntC      (4847.875,4876.625)  [4827.875:4847.875], [4876.625:4891.625]*
# Note the * in the mid-point continuum adjustment.
##### Spline continuum example #####
# ID           Line Band Pass           Points for a Spline Cont.           S/N cont.
# spline      (4847.875,4876.625) {4827.875,4833.0,4847.875,4876.625,4891.625}<4880:4890>
#####
#
#           Intervals for Mean continuum
#           see Bica (1986)
#
#####
#
Cont. |5290:5310,5303:5323,5536:5556,5790:5810,5812:5832,5860:5880,6620:6640|
```

Table 1 Example of input table. A # indicates that the line is not used in the computations. Note the * in the mid-point continuum adjustment. A full table is available at <http://www.if.ufrgs.br/~riffel/software.html>.

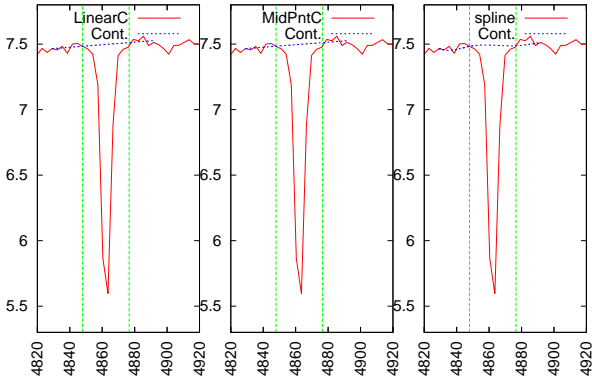


Fig. 3 Example of PACCE output plots using Tab. 1 index definitions. Mid-point, linear and spline pseudo-continuum adjustments were used in left, center and right plots respectively. The shown region is around H β absorption line.

the measurements and make a histogram of these differences to give a better idea of the dispersion between both sets. It is clear from Fig. 4 that PACCE does reproduce very well the *splot* “manual” W_λ values. Note that there seems to be a very slight systematic under-prediction of the W_λ computed with PACCE if compared with those of *splot*, however, the differences are $\lesssim 0.05\text{\AA}$. Similar results were obtained by Sousa et al. (2007, see their Fig. 6), thus, suggesting that IRAF *splot* measurements may slightly overestimate the W_λ values.

It is even harder to properly measure W_λ in observed spectra than in theoretical ones. To properly test our code capability in dealing with real spectra we have measured a set of W_λ ($\sim 950W_\lambda$) in the library of observed stellar spectra presented by Silva & Cornell (1992). The results of such test are shown in Fig. 5. It is clear that PACCE is able to properly reproduce the measurements of *splot* task. However, a larger dispersion in the differences is observed between both measurements than when using SSP models. In addition, these differences are clearly within the errors and are lower than $\sim 0.5\text{\AA}$.

5 Final Remarks

We present PACCE a Perl algorithm to compute continuum and W_λ . We describe the method used in the computations, as well as the requirements for its use.

We compare the measurements made with PACCE and “manual” ones made using IRAF *splot* task. These tests show that for SSP models (i.e. high S/N) the W_λ values are very similar (differences $\lesssim 0.2\text{\AA}$). In real stellar spectra, the correlation between both values is also very good, but with differences of up to 0.5\AA . However, these small differences can be explained by the intrinsic errors in subjectiveness determinations of continuum levels caused in “manual” measurements.

PACCE is also able to determine mean continuum and continuum at line center values, which are helpful

in stellar population studies. In addition, it is also able to compute the $\sigma(W_\lambda)$ using photon statistics.

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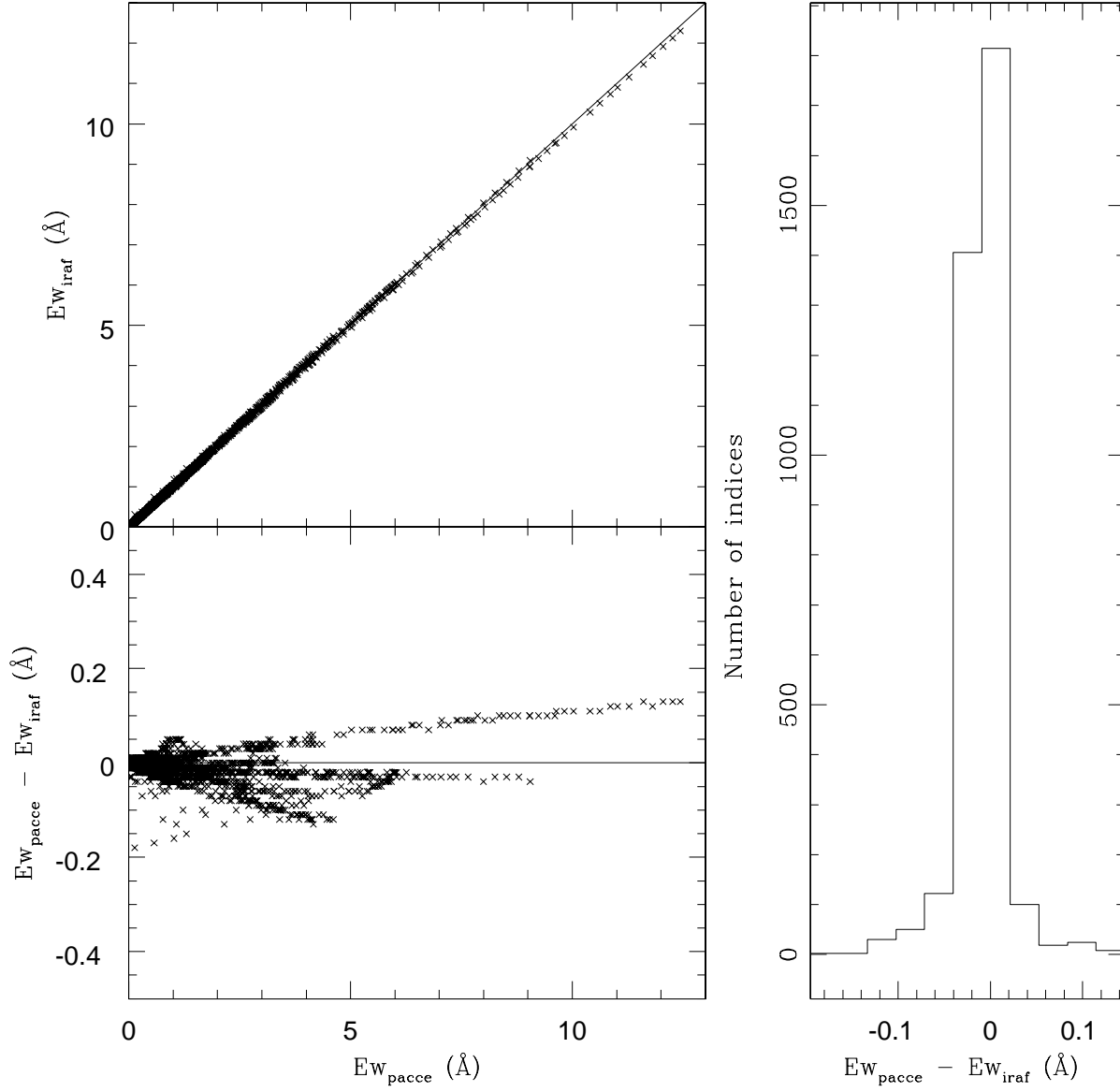


Fig. 4 Comparison of PACCE and “hand made” IRAF SPLOT measurements using Maraston (2005) theoretical models. Solid line is the equivalence line. At the differences and a histogram of them are shown in bottom and right side, respectively.

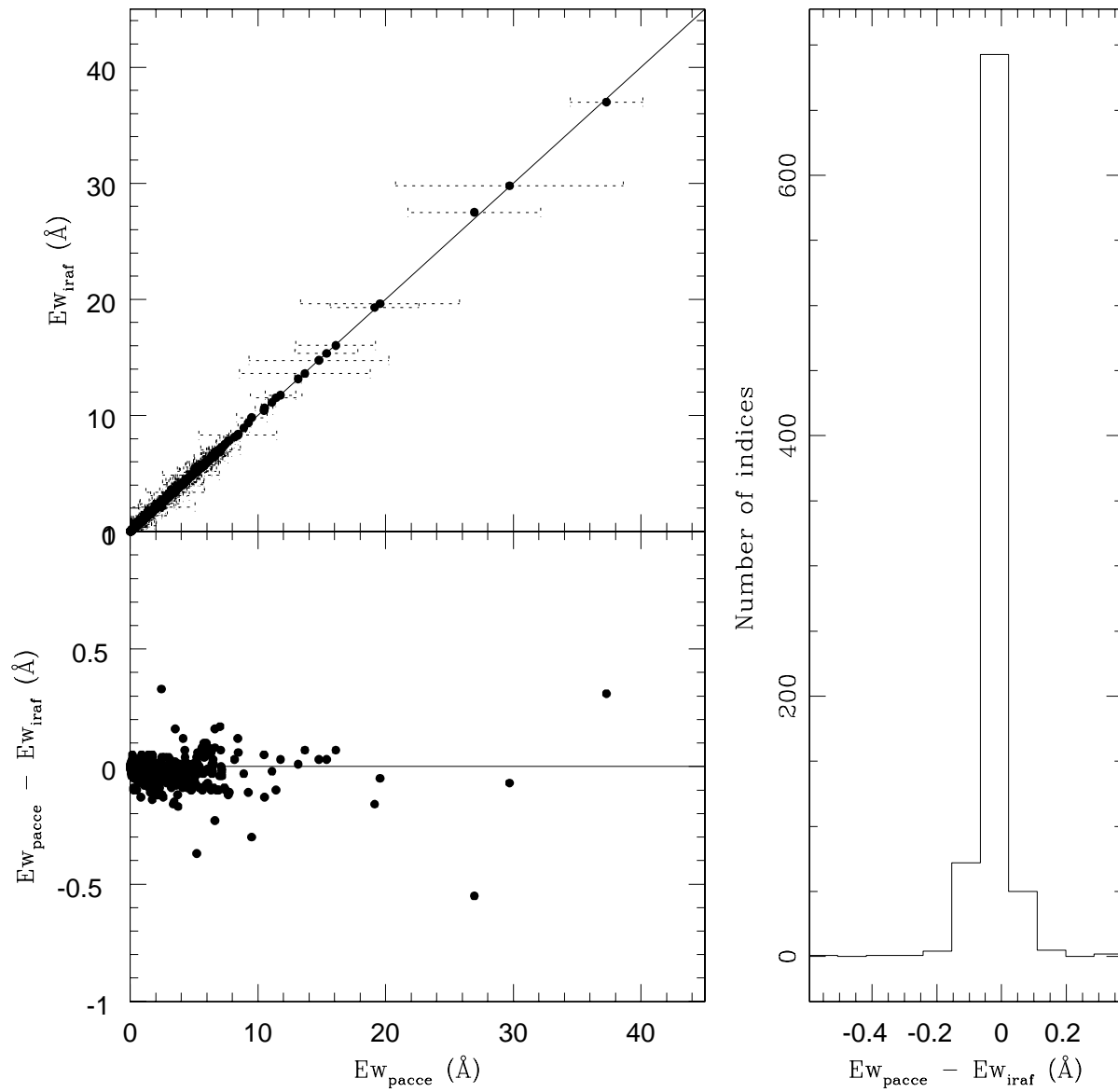


Fig. 5 Same as Fig. 4 but for observed optical stellar spectra. Error bars are shown.

References

- Bica, E. 1988, A & A, 195, 76.
- Feltzing, S. & Gonzalez, G., 2001, A&A, 367, 253.
- Gonzalez, G. & Lambert, D. L. 1996, AJ, 111, 424.
- Krabbe, A. C., Rembold, S. B. & Pastoriza, M. G., 2007, 2007, MNRAS, 378, 569.
- Krabbe, A. C.; Pastoriza, M. G.; Winge, C.; Rodrigues, I.; Ferreira, D. L., 2008, MNRAS, 389, 1593.
- Maraston, C., 2005, MNRAS, 362, 799.
- Pogge, R. W., & Owen, J. M. 1993, OSU Internal Report 93-01
- Rembold, S. B. & Pastoriza, M. G., 2007, MNRAS, 374, 1056
- Rickes, M. G., Pastoriza, M. G. & Bonatto, Ch., 2004, A&A, 419, 449
- Riffel, R.; Pastoriza, M. G.; Rodriguez-Ardila, A. & Maraston, C., 2008, MNRAS, 388, 803.
- Schmitt, H. R., Bica, E., & Pastoriza, M. G. 1996, MNRAS, 278, 965
- Silva, D. R.; Cornell, M. E., 1992, ApJS, 81, 865.
- Sousa, S. G., Santos, N. C., Israelian, G., Mayor, M. & Monteiro, M. J. P. F. G., 2007, A&A, 469, 783.
- Vollmann, K. & Eversberg, T., 2006, AN, 327, 862.
- Worthey, G.; Faber, S. M.; Gonzalez, J. J. & Burstein, D., 1994, ApJS, 94, 687.